The Baryon Asymmetry of the Universe

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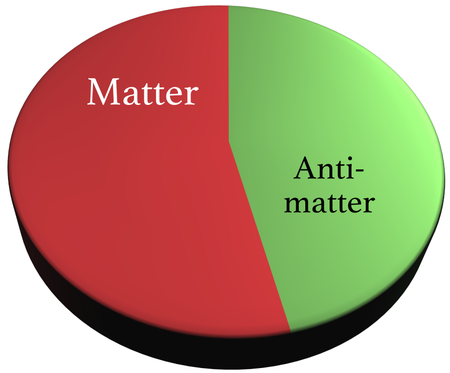
Snowmass RF Town Hall Meeting Oct 2

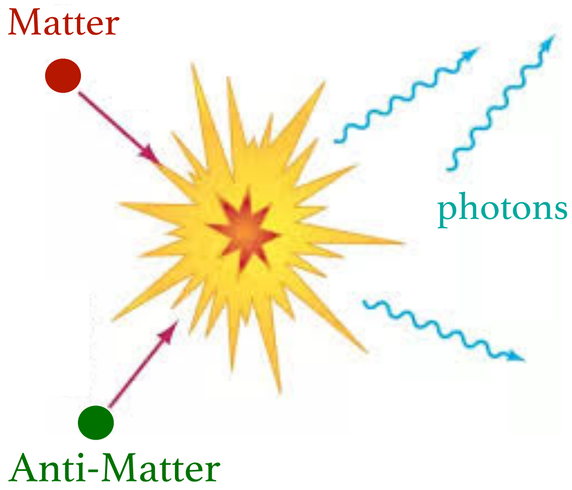
RF4 topical group

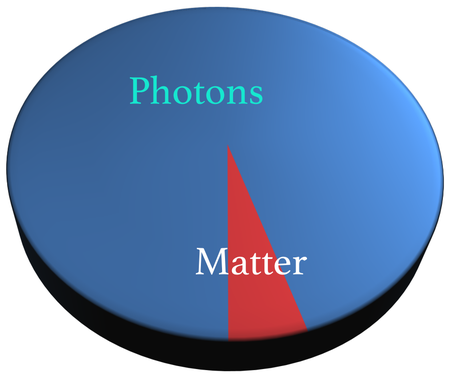
LOI submitted by: Gilly Elor, Julia Harz, Seyda Ipek, and Bibhushan Shakya

Baryogenesis

What mechanism generated the primordial baryon asymmetry of the Universe?







Observation (CMB, BBN):

$$Y_B^{\rm meas} \equiv \frac{n_b - n_{\bar{b}}}{s} = 8.7 \times 10^{-11}$$

Baryogenesis

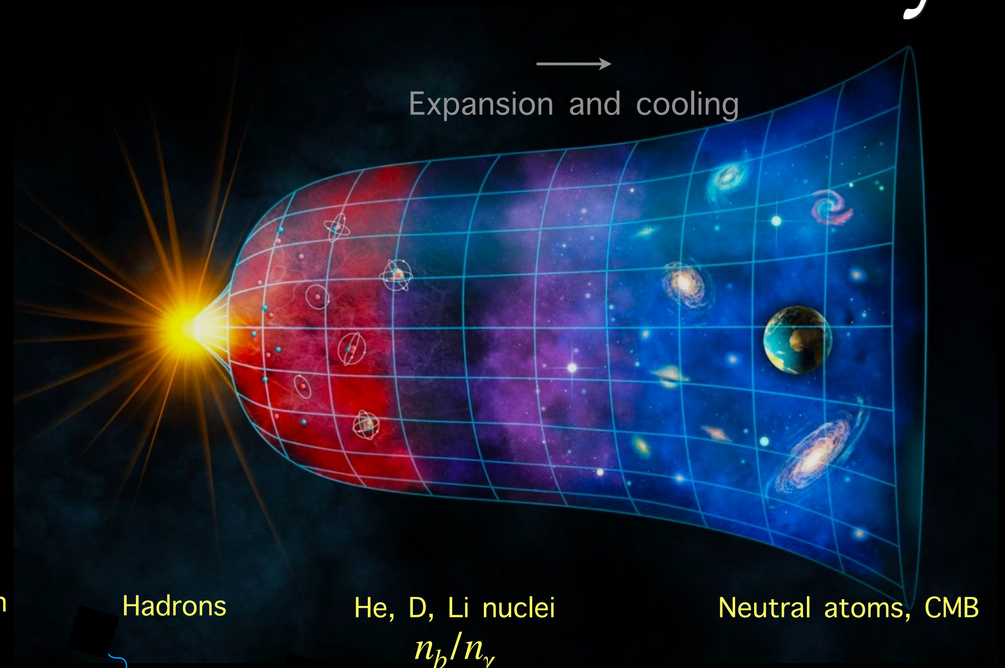
Need to go Beyond the Standard Model (BSM)

The Sakharov conditions:

- Baryon number violation.
- Conjugate rates must be different (CP violation).
- Out of thermal equilibrium.

B violation	CP violation	Out of equilibrium
Sphalerons	new CP violation in quarks	Cosmological phase transitions
Explicit B violation	new CP violation in leptons	out-of-equilibrium decays
Explicit L violation	new CP violation in scalars	*chemical potential*
Some other particle-number violation	CP violation in a dark sector	

High vs Low Scale Baryogenesis



Standard Model Particles in Thermal Equilibrium

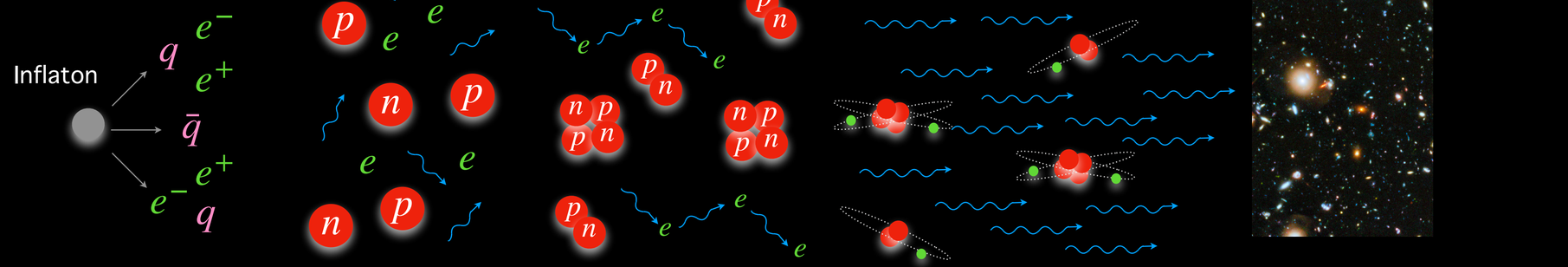
Hadrons

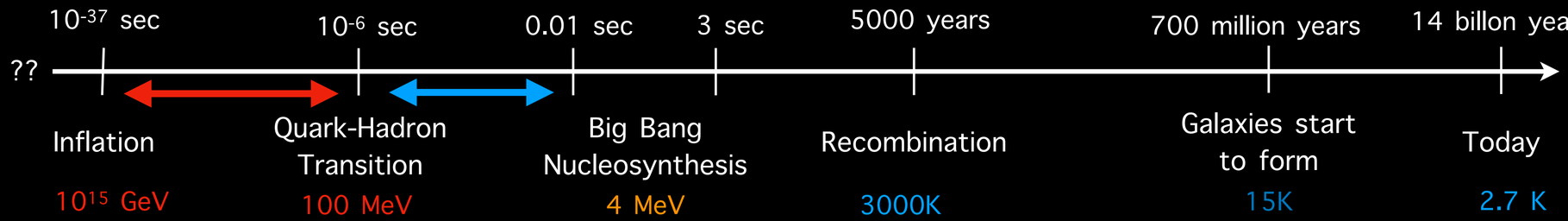
He, D, Li nuclei

n_b/n_γ

Neutral atoms, CMB

Galaxies, Earth, you.





G. Elor

Physics motivation for a white paper

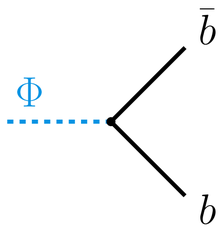
- A concrete summary of the traditional options for generating the baryon asymmetry (generally not testable).
- Overview of new proposals of baryogengesis - low scales.
- Experimental connections.

Of particular relevance to RF-4: new mechanisms for low scale baryogengesis that can be searched for in B and L violating processes.

Baryogenesis from B Mesons

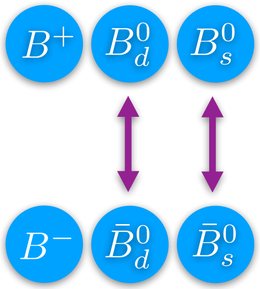
G. Elor, M. Escudero, A. Neslon [*arXiv: 1810.00880 PRD*]

Out of equilibrium late time decay



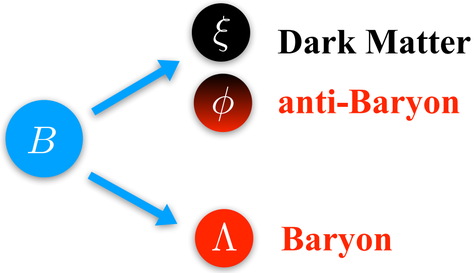
$T_{\rm RH} \sim 20\,{\rm MeV}$

CP violating oscillations



$A_{\ell\ell}^d \quad A_{\ell\ell}^s$

B-mesons decay into Dark Matter and hadrons



${\rm BR}(B \to \phi\xi + {\rm Baryon} + ...)$

$\Rightarrow$

Baryogenesis

$Y_B = 8.7 \times 10^{-11}$

&

Dark Matter

$\Omega_{\rm DM} h^2 = 0.12$

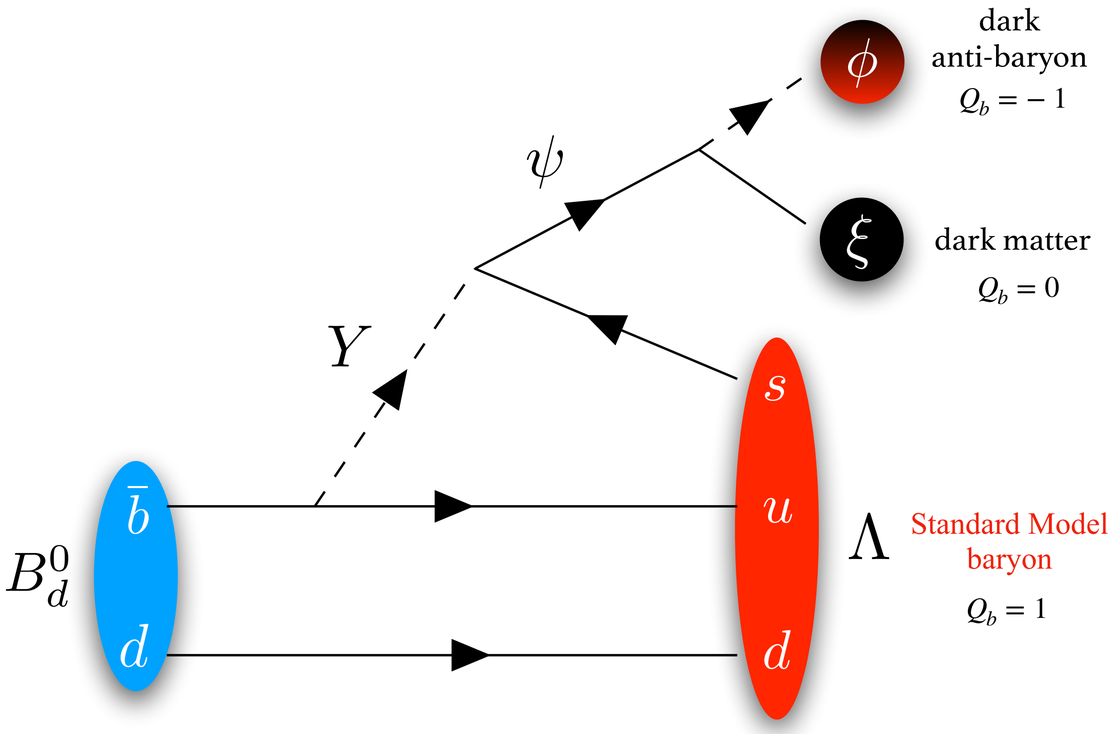
$$Y_B \propto \sum_{q=s,d} A_{\ell\ell}^q \times {\rm Br}(B_q^0 \to \phi\,\xi + {\rm Baryon} + X)$$

$$A_{\ell\ell}^q = \frac{\Gamma\left(\bar{B}_q^0 \to B_q^0 \to f\right) - \Gamma\left(B_q^0 \to \bar{B}_q^0 \to \bar{f}\right)}{\Gamma\left(\bar{B}_q^0 \to B_q^0 \to f\right) + \Gamma\left(B_q^0 \to \bar{B}_q^0 \to \bar{f}\right)}$$

Experimental observables!

Exotic "B violating" decay

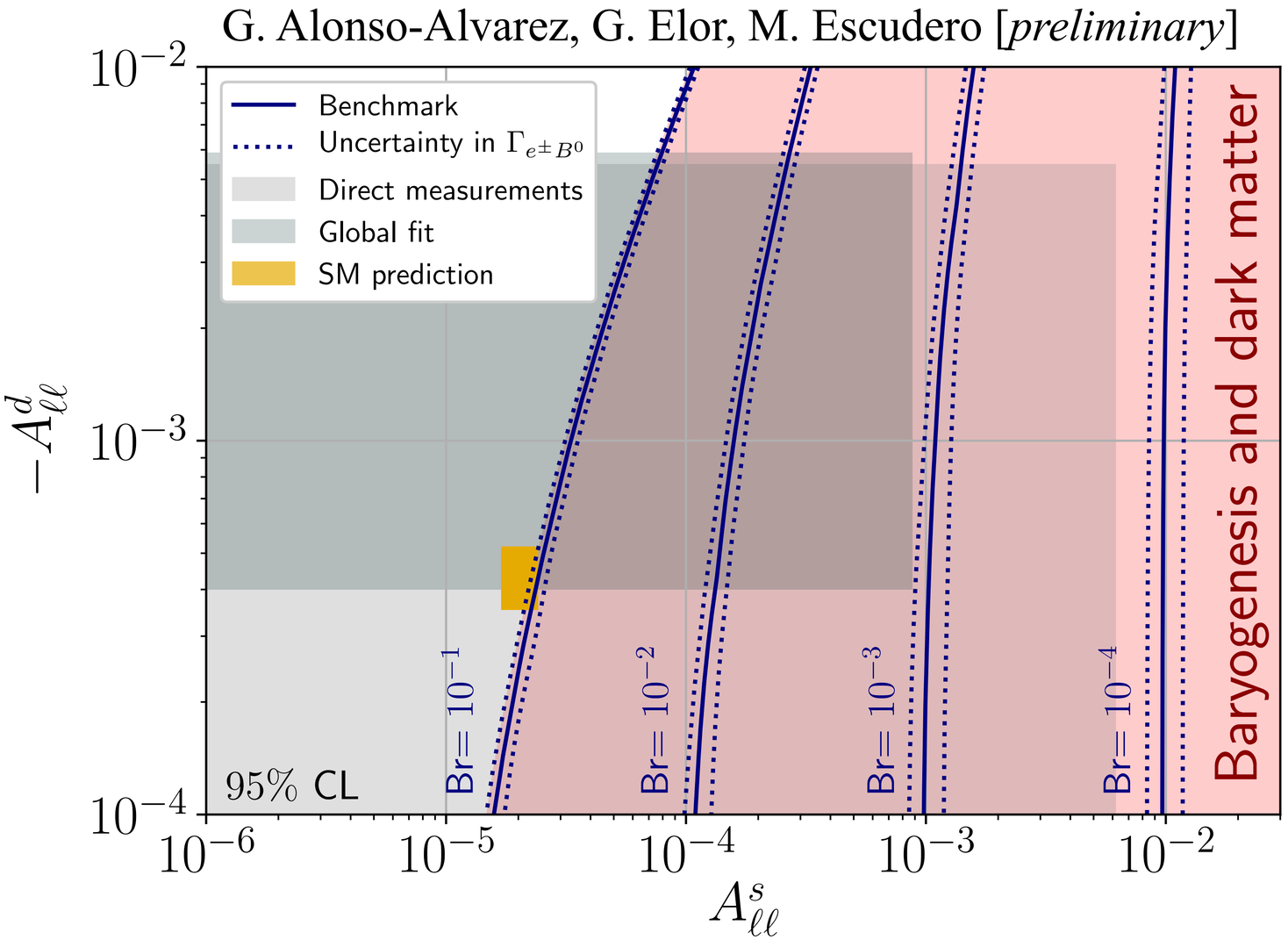
Searches underway by Belle, Belle-II, BaBar!



$$\mathrm{Br}(B_q^0 \to \phi\,\xi + \mathrm{Baryon} + X)$$

Operator/Decay	Initial State	Final state	ΔM (MeV)
$\mathcal{O} = \psi\, b\, u\, d$	B_d	$\psi + n\,(udd)$	4340.07
	B_s	$\psi + \Lambda\,(uds)$	4251.21
$\bar{b} \to \psi\, u\, d$	B^+	$\psi + p\,(duu)$	4341.05
	Λ_b	$\bar{\psi} + \pi^0$	5484.5
$\mathcal{O} = \psi\, b\, u\, s$	B_d	$\psi + \Lambda\,(usd)$	4163.95
	B_s	$\psi + \Xi^0\,(uss)$	4025.03
$\bar{b} \to \psi\, u\, s$	B^+	$\psi + \Sigma^+\,(uus)$	4089.95
	Λ_b	$\bar{\psi} + K^0$	5121.9
$\mathcal{O} = \psi\, b\, c\, d$	B_d	$\psi + \Lambda_c + \pi^-\,(cdd)$	2853.60
	B_s	$\psi + \Xi_c^0\,(cds)$	2895.02
$\bar{b} \to \psi\, c\, d$	B^+	$\psi + \Lambda_c\,(dcu)$	2992.86
	Λ_b	$\bar{\psi} + \overline{D}^0$	3754.7
$\mathcal{O} = \psi\, b\, c\, s$	B_d	$\psi + \Xi_c^0\,(csd)$	2807.76
	B_s	$\psi + \Omega_c\,(css)$	2671.69
$\bar{b} \to \psi\, c\, s$	B^+	$\psi + \Xi_c^+\,(csu)$	2810.36
	Λ_b	$\bar{\psi} + D^- + K^+$	3256.2

CP Violation in B mesons



Other Signals of Baryogengesis

- Apparent L violation in pion decays [G.Elor, R. McGehee, [*to appear*]]
- Neutron-Antneutron oscillations can be excellent probes of various viable baryogengesis mechanisms [C. Grojean, B. Shakya, J. Wells, Z. Zhang [*arXiv:1806.00011*]]
- Long lived decays at colliders [G. Alonso-Alvarez, G.Elor, A. Neslon, H. Xiao [*arXiv:1907.10612 JHEP*]], [K. Aitken, D. McKeen, A. Nelson, T. Neder [*arXiv:1708.01259 PRD*]]
- ….

Goals and Timeline of a White Paper

- Physics Goals: Summary of the existing mechanisms of baryogengesis with an emphasis on possible experimental efforts for testability.
- Community Goal: Stronger and larger baryogenesis community in the United States. Continue to bring theorists and experimentalists together.
- Timeline: Recruiting contributors by December, and publishing a white paper in May.

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Thank you